Design of Rail Instrumentation for Wind Tunnel Sonic Boom Measurements and Computational-Experimental Comparisons

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Abstract: An innovative pressure rail concept for wind tunnel sonic boom testing of modern aircraft configurations with very low overpressures was designed with an adjoint-based solution-adapted Cartesian grid method. The computational method requires accurate free-air calculations of a test article as well as solutions modeling the influence of rail and tunnel walls. Specialized grids for accurate Euler and Navier-Stokes sonic boom computations were used on several test articles including complete aircraft models with flow-through nacelles. The computed pressure signatures are compared with recent results from the NASA 9- x 7-foot Supersonic Wind Tunnel using the advanced rail design.

Keywords: Sonic Boom, Supersonic Flow, Numerical Algorithms, CFD.

1 Introduction

Sonic boom elimination is the largest technical hurdle to overcome for worldwide entry of commercial supersonic transports. The Supersonics Project under NASA's Fundamental Aeronautics Program is developing technologies to enable future civilian aircraft to fly efficiently with reduced sonic boom, noise, and emissions. CFD and experimental techniques are synergistically advancing design and prediction capabilities. A novel concept to improve the accuracy and efficiency of wind tunnel sonic boom testing was brought to fruition using domain rotation and solution-adapted adjoint computational methods [1] to develop an advanced pressure rail. Sonic boom prediction accuracy is improved by use of grids that are sheared at the Mach cone angle and adjusted for angle of attack and stretched in the direction of the shock wave with unstructured tetrahedral flow solvers [2].

2 Applications and Results

Computational and experimental methods for accurate sonic boom prediction will be presented in the proposed paper. Figure 1 shows the surface pressure coefficient contours on the model, rail, tunnel wall, and the plane of symmetry. The solution was obtained using CART3D with the AERO module and solution-adapted meshing with the domain rotated to align with free stream Mach angle [1]. The profile of the mid-section of the rail is also shown in the figure. The rail was designed to minimize flow disturbances and eliminate shock reflections from the orifice plane. The

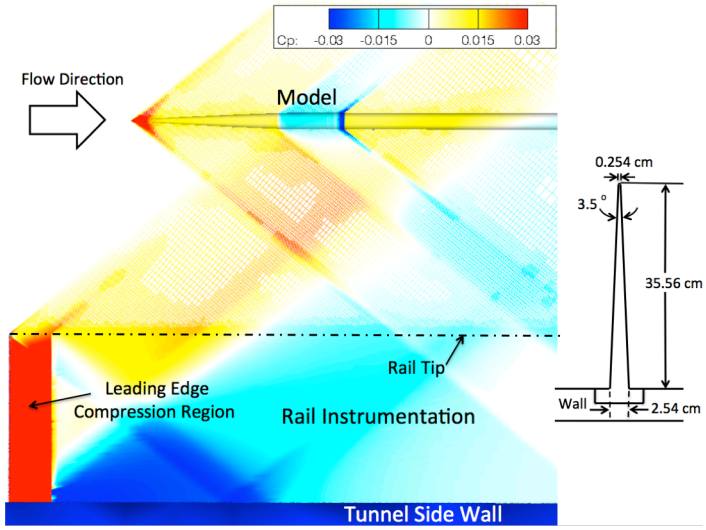

Fig. 1. CART3D solution and mesh of model, rail, & wall.

large standoff distance from the wall places any possible model shock reflections from the tunnel wall down stream of the pressure signature. Pressure signatures are measured along 167.62 cm of rail length (total rail length is 228.58 cm) at the apex of the rounded tip with 420 equally spaced static pressure orifices. Without the advantage of the solution-adapted Cartesian grid method for sonic boom prediction the new rail design would not have been possible. The rail was shown to successfully model the free-air model pressure signatures regardless of the separation distance between rail and test article, indicating that the model's shock passing through the rail's leading edge shock does not alter the model's signature on the rail. The computational results and analysis methodology for rail design will be presented in detail in the proposed report.

The Lockheed Martin Aeronautics Company under a NASA Research Award has designed a low boom configuration to meet NASA's stringent environmental targets and performance goals. The configuration was recently tested with the pressure rail instrumentation in the NASA Ames Supersonic wind tunnel. Computations of the Lockheed test configuration and two axisymmetric bodies-of-revolution test articles were obtained with specialized grids developed to accurately capture the sonic boom pressure signatures using Mach cone aligned prismatic cells with AIRPLANE and USM3D. The prismatic cells are subdivided into tetrahedral elements and are stretched to reduce the effects of dissipation in the shock wave propagation direction while very fine grid spacing in the axial direction is preserved. The viscous grids were developed for the wind tunnel Reynolds number of 4.33 million per foot. Figure 2 shows a turbulent flow solution using the Spalart-Allmaras turbulence model compared with the Lockheed configuration test data and an Euler solution. The viscous solution shows excellent agreement with the test data obtained with the rail instrumentation. The inviscid computation shows discrepancies near the peak overpressure in the region where the blade sting attaches to the model. Two types of model support hardware were tested and will be compared with computations, and both turbulent and laminar flow solutions will be presented in the proposed paper.

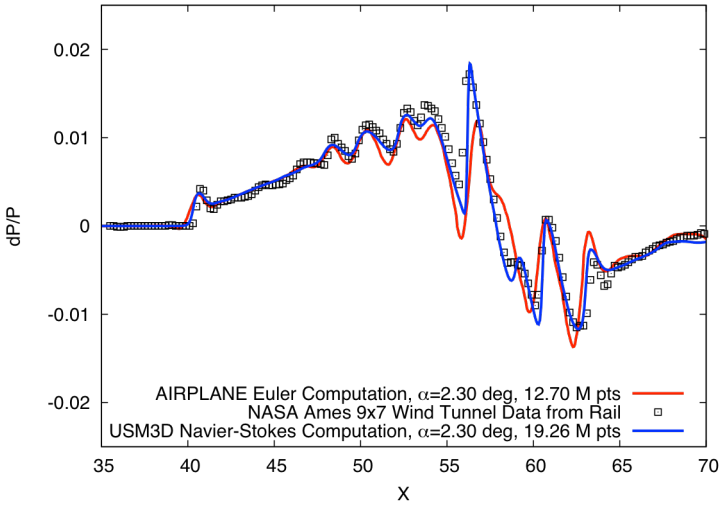

Figure 2. Lockheed Martin Configuration, Mach 1.6, height 80.8 cm.

3 Summary

The accuracy of computational and experimental sonic boom predications has improved significantly. Controlling humidity and pressure are paramount to the experimental accuracy improvements. Some discussion of the experimental approach and data processing methods will be presented. The small surface differences between the "as-designed" and "as-built" wind tunnel models may lead to further corroboration of the data. Computations of the as-built geometry are planned and will be compared with experiment.

References

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